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GRAPHICAL-DATA-PROCESSING RESEARCH STUDY AND EXPERIMENTAL INVESTIGATION

TENTH QUARTERLY REPORT

By

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ABSTRACT

These Quarterly Reports describe the continuing development of scanning, preprocessing, character-classification, and context-analysis techniques for hand-printed text, such as computer coding sheets in the FORTRAN language.

During the period of this report, our effort was directed toward preparations for the delivery of the MINOS III facility. This effort included the development of a diagnostic program and operating program for the facility, software and hardware documentation, and the creation of a link allowing the computer to output quantized character images to the 1024-image preprocessor. This link is described in some detail.

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ILLUSTRATIONS

I INTRODUCTION AND SUMMARY

This report describes the continuing development of scanning, preprocessing, character-classification, and context-analysis techniques for hand-printed text. The particular subject matter of our investigation is hand-printed FORTRAN text on standard computer coding sheets, with a 46-character alphabet. The reader is referred to the previous reports of this project for background and supplementary material.

In the period covered by this report, our effort was directed toward preparations for the delivery of the MINOS III facility. This effort was carried forward on a number of fronts, including software development, software documentation, hardware documentation, and the creation of a link allowing the SDS 910 computer to output quantized character images to the 1024-image preprocessor.

In the area of software development, an extensive diagnostic program for the MINOS III facility has been largely written. The diagnostic program has two general areas. One deals with the TV and image-processing components of the facility, namely, the TV camera, the TV shift-register interface, the TV monitor, the display oscilloscope, the TV camera drive motors and position sensors, the 1024-image preprocessor, and the simulated preprocessor. The diagnostic program accepts typed commands from the operator that cause any of these units to be operated, and the results to be presented to the operator. An additional facility allows arbitrary 24x24 images to be read in from paper tape or typed in at the console. These images can then be used to test the components of the facility, such as the 1024-image preprocessor.

The other general area of the diagnostic program deals with MINOS II itself. It allows the weights of MINOS II to be set, examined, zeroed, saturated, and adapted under the control of the operator. In addition to providing "fingertip control" of the basic MINOS II actions, it has provisions for special operating sequences. For example, a single command will cause a graph of the operating characteristic of a DPU to be made and displayed.

The TV area of the diagnostic program has been written and checked out. The MINOS II area has been largely written, and its checkout awaits circuit improvements to MINOS II. We will not describe the diagnostic program and its operation here, but will reserve the description until the program is completed.

The operating program, which includes the scanning, preprocessing, and classifying functions, is currently being assembled. The components of the operating program are all in hand: SCAN 3, PREP 24A, CALM, and routines for operating MINOS II. These are being combined in a coordinated package.

In the area of software documentation, the Aegean stables of software and write-ups that have resulted from four years of program development by various individuals are being cleaned out and transformed into a few well-organized notebooks. Present plans call for one notebook to contain general facility software documentation, another to contain the descriptions and listings of the many library subroutines we have developed, and a third to contain the descriptions and listings of the diagnostic program, operating program, and miscellaneous utility programs. Together, these notebooks will provide a convenient and self-contained operating manual.

Hardware documentation is proceeding apace with software documentation. The hardware documentation includes drawings of MINOS II and the interface and supporting writeups.

As described in the following sections, the MINOS III facility in its previous form lacked the capability for the transfer of scanned, quantized images from the computer memory to the 1024-image processor. This missing link has been provided with the modification of the TV shift-register interface.

II COMPUTER OUTPUT OF QUANTIZED IMAGES TO THE 1024-IMAGE PREPROCESSOR

A. Introduction

In preceding reports (Reports No. 20 and 21, Quarterly Progress Reports No. 8 and 9 of Contract DA 36-039 AMC-03247 (E)), we described the shift-register TV interface that was added to the MINOS III facility (then called the MINOS II - SDS 910 Facility) in 1965. This interface allows quantized pictures to be read in from the Dage television camera to the SDS 910 computer at a resolution of either 24x24 or 120x120 black/white picture elements. The TV interface has been used to input a variety of materials, including 120x120 pictures to be analyzed by the TV O.P. 120 Program, 24x24 images for direct preprocessing, and hand-printed characters from computer coding sheets.

Our view of the overall MINOS III facility at the time the TV interface was established is reflected in Fig. 1, which also appeared in Report No. 22, the final report of the above-referenced contract. In that report we emphasized the flexibility obtained through the presence of parallel paths for the preprocessing and classification functions. Each function could be performed by a hardware unit (the 1024-image preprocessor in the former case, and the MINOS II learning machine in the latter) or by a software simulation in the SDS 910 computer. This parallelism allowed comparison of the hardware and software subsystems, and such comparisons were indeed carried out and described in Reports No. 21 and 22. The data for the comparison experiments consisted of map symbols on slides presented by a conventional projector.

From the vantage point of our more recent experience, however, it can be seen that the earlier picture was incomplete. When we changed from map symbols presented on slides in a fixed location to hand-printed characters gathered dynamically from a coding sheet, the problem of scanning (or selective attention) was introduced. Working from

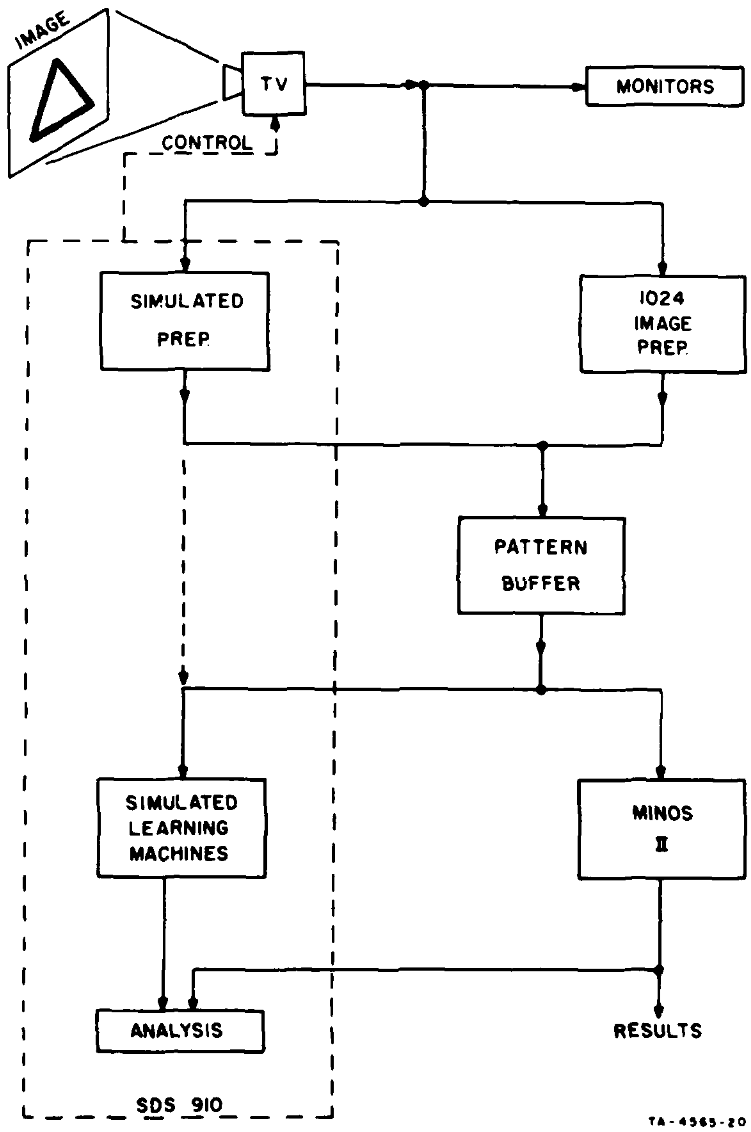

FIG. 1 EARLY FACILITY DIAGRAM

a coding sheet, the TV camera input to the computer a 120x120 field of view, and the computer scanned the information in this field to find, isolate, and center individual character images for preprocessing. Thus, by the time a character image was isolated by the scanning procedure, it resided in the computer. The input link to the 1024-image preprocessor, however, came directly from the TV camera, working in 24x24 resolution mode. In short, scanned images could not be sent from the computer to the hardware preprocessor; they could only be preprocessed by the software simulation.

The missing link has been supplied by the facility modification described in this section. With this link, the facility diagram takes on the form shown in Fig. 2. It becomes possible to preprocess and classify scanned character images with either the hardware or software subsystems.

B. Description of the Method

The underlying TV input system is based on a standard closed-circuit TV chain, which includes a camera, control unit, and monitor. This TV chain is free-running; that is, it continually generates frames from the TV camera at the rate of two interlaced fields every 1/30 second, without direction from the computer. In the quiescent state, the video signal is merely presented to the TV monitor, either directly or through a Schmidt trigger that quantizes the video to two levels, black and white.

When the computer requests the input of a picture from the TV camera, the quantized video signal is gated and shifted, bit by bit, into a 24-bit shift register under the control of a timing clock. When the shift register has accumulated 24 bits, representing a horizontal segment of a quantized TV image, the contents of the register are dumped into the computer in parallel by a PIN instruction.

If 24x24 input has been requested, the timing is such that the accumulated 24 bits span an entire horizontal scan line. Every tenth scan line is sent to the computer, for a total of 24 lines. If 120x120

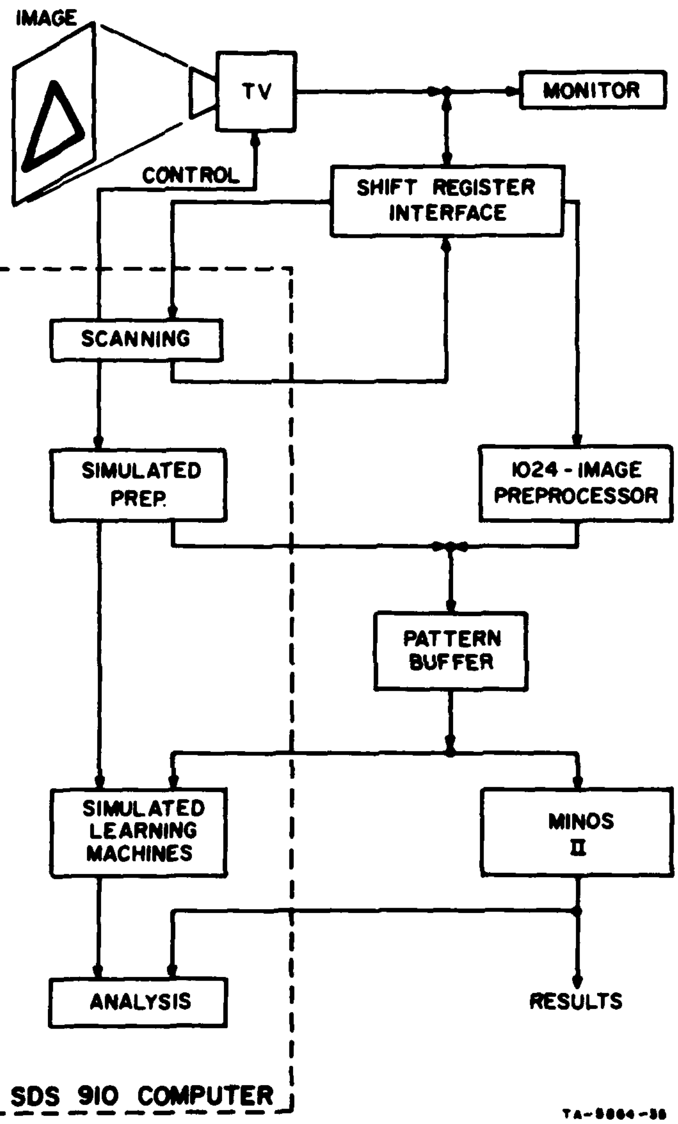

FIG. 2 DIAGRAM OF THE MINOS III FACILITY

input is requested, every second scan line is sent to the computer, for a total of 120 lines. The timing is then set so that the accumulated 24 bits on a line cover only 1/5 of a horizontal scan line, and the picture is read in the form of five columns obtained in successive TV fields. This input operation is described in more detail in Reports No. 21 and 22.

The desired output link from the computer to the 1024-image preprocessor was roughly the converse of the TV input link. Instead of sampling the quantized video information from the TV system to obtain a 24x24 array of bits in the computer, we wanted to generate, from each bit in such an array, a black or white patch covering 1/24 x 1/24 of the video scan raster. These patches would be reassembled into a complete TV waveform, which would then be available to the projection tube, which would in turn present the image optically to the preprocessor.

Only 24x24 output from the computer was implemented. It would have been impossible for the computer to maintain the output rates required for a 120x120 picture, without additional external storage. In addition, there was no need to send a 120x120 picture to the preprocessor.

The black or white patch corresponding to one bit of the quantized picture consisted of a black or white video level maintained for 1/24 of the effective horizontal scan time, injected into the TV system at the appropriate time on ten successive scan lines. The key element required was a storage mechanism capable of recirculating 24 bits of information (comprising one row of the picture) and presenting these bits to the TV system at the proper times. Fortunately, the key element was already at hand, namely, the 24-bit shift register used for picture input.

Instead of shifting picture bits into the shift register one by one and then dumping them into the computer, we fill the register all at once from the computer and shift bits out of the end of the register to control the level of the video waveform. By connecting the shift register to recirculate, we arrange that the same bit pattern is automatically impressed on ten successive scan lines, after which the contents of the shift register are replaced for the next picture row.

Because of the close relation between the mechanism of 24x24 picture input and that of 24x24 picture output, the timing circuitry already existing for the former was just what was needed for the latter. In particular, the circuits that marked off 24 points along a scan line and chose every tenth line for input were allowed to operate in their usual fashion, and we merely tapped into these circuits as required to regulate the output.

There is no need for communication with the 24-bit shift register during the presentation of the ten horizontal scan lines that comprise one row of the output picture. Because the shift register is connected in recirculating fashion for this operation, it has completed one full cycle after the 24 bits have been sent to the video system, and it is automatically ready for the next line. The transition between rows, however, introduces a definite communication requirement. During the tenth (and last) line of one picture row, the shift register contains the information for that row. By the time the first scan line of the row following is to be injected into the video system, the shift register must contain the information for that row. Each video scan line takes approximately 63.5 μs. Of this time, approximately 45 μs is spent in the horizontal sweep and the remainder is spent in the horizontal retrace. This retrace time of approximately 15 μs is the time available for updating the information in the shift register.

The most obvious way to update the shift-register information would be to send a 24-bit word from the computer with, for example, a POT instruction. However, in the construction of the interface only 14 of the 24 data lines from the computer were carried to the interface that includes the shift register. Therefore, implementing direct computer output to the shift register would require extensive hardware additions. On the other hand, it would be impossible to send the information from the computer to the shift register in two or more pieces, because 15 μs is less than two machine cycles of the SDS 910 computer.

What was needed, therefore, was an external storage unit capable of holding 24 bits that could be filled from the computer at a more leisurely pace and dumped into the shift register during the 15-μs re-

trace period. Again, fortunately, this element was already at hand in the form of the MINOS pattern buffer. The buffer is arranged in two parts, 144 bits (flip-flops) in the upper half or "upper buffer" and 120 bits in the lower buffer. (The buffer was described in Report No. 16.) Any 24 bits of the buffer could, in principle, be used to hold a picture row for transfer to the shift register on demand. As a practical matter, we chose to use the unpaired 24 bits at the end of the upper buffer. These bits, originally designed to hold a pattern-identifying serial number on input from an external paper-tape reader, were effectively unused in the present form of the system. This meant that they had the least circuit loading of any flip-flops in the buffer.

Thus, the last three ranks (24 bits) of the upper buffer were wired to dump information into the shift register at the proper times. The details of how the information flow is controlled from the computer are described in the next subsection.

By utilizing the existing elements of the TV system and the interface--the video chain, the shift register and its associated timing, and the MINOS pattern buffer--we were able to construct the output link with a bare minimum of equipments additions and development effort.

C. Details of Operation

The upper buffer is constructed in the form of a shift register, eight bits wide and 18 bits long. The 24 bits that are used for transfer to the TV shift register comprise the last three ranks of the buffer. The computer enters the first picture row into the buffer by breaking it into three eight-bit parts, shifting these into the first three ranks of the buffer and then executing 15 more shifts to carry the data to the last three ranks. As these shifts are performed, the second, third, fourth, fifth, and sixth picture rows (each broken into three eight-bit pieces) are entered into the front of the upper buffer in order. Later, after the TV shift register has accepted the first picture row from the upper buffer, the act of shifting the seventh picture row into the front of the buffer also advances the second picture row into position for the next transfer to the shift register.

To summarize, a quantized 24x24 image is initially stored in the computer in the following standard format:

Location	N	1A	1B	1C
	N+1	2A	2B	2C
	.	.	.	.
	.	.	.	.
	N+23	24A	24B	24C

where we have explicitly indicated the eight-bit fields, A, B, and C, of each row. The top of the picture, row 1, is stored in the lowest-numbered memory location (N). The left-hand side of the picture, A, is stored in the most significant portion of the computer word. The computer pre-loads the upper buffer by shifting in 18 fields in the order 1C, 1B, 1A, 2C, 2B, 2A,..., 6C, 6B, 6A. The computer then initiates the TV output activity. When the computer finds that the first picture row has been sent to the TV shift register, it shifts 7C, 7B, and 7A into the buffer. This procedure is repeated row by row; after sending the 24th row the computer returns to the first row so that when the entire picture has been sent to the TV system the first six rows are again in the buffer ready to continue with the next presentation. This process is repeated as long as it is desired to maintain the picture.

The leftmost picture elements (from the A fields) are sent to the leading end of the TV shift register, so that they are the first to be impressed onto the video system.

It is seen that this process demands full-time attention by the computer while a picture is being output. Lacking 576 bits of external storage, we had no way to establish a self-refreshing output.

The complete procedure for picture output from the computer is performed by a FORTRAN-compatible subroutine called TVOUT. TVOUT has two calling arguments. The first specifies where the picture is stored in memory; the second gives the number of video fields to be output at 1/60 s each.

After preloading the buffer as described above, the subroutine executes two instructions (EOM 33057 and EOM 33042) that set the TV

circuitry to perform one video output field and to operate at 24x24 resolution. The subroutine then goes into a loop in which it breaks the upcoming picture line (initially the seventh) into three parts, waits for the transfer from the buffer to the shift register (completion of this transfer is tested by the instruction SKS 30020), and shifts the upcoming line into the buffer. Whenever the line count indicates that the 24th line has been sent to the shift register, the routine increases the TV field count. If the field count does not yet equal the desired amount, the routine executes the EOM instructions to request another video field and returns to the loop. When the field count is satisfied, the subroutine returns control to the program that called it. The TV system, not receiving an output request, reverts to its normal mode of operation.

When the TV output operation is performed, the picture appears on the TV monitor. There it may be viewed to provide an immediate and convenient check on the operation of the output system.

Figure 3 shows the monitor display of a 24x24 pattern of alternating 1 bits and 0 bits. The bit pattern is reversed in every picture row to form a checkerboard pattern.

Figure 4 shows the monitor display of a quantized, hand-printed letter B (Serial No. 200). This is the same image that would appear on the projection tube and be projected into the 1024-image preprocessor. In Fig. 5, we display the same character in a typed representation, in which a typed "O" indicates a dark element. (The aspect ratio of Fig. 5 is distorted because of the different vertical and horizontal spacings of the typewriter.) The display in Fig. 4 looks more angular and jagged than the other representation, but this only reflects the difference between the human perceptual response to the two. In Fig. 5, perceptual smoothing can occur. The information contained in both pictures is the same.

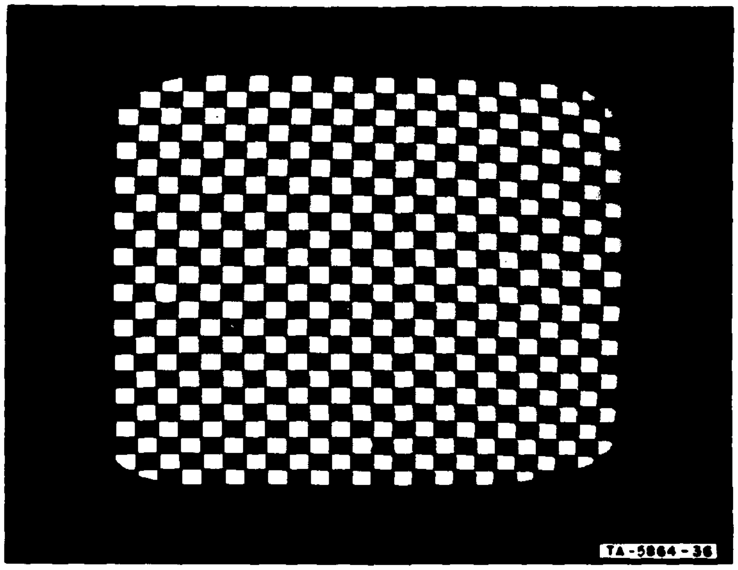

FIG. 3 TV MONITOR DISPLAY OF A CHECKERBOARD PATTERN FROM THE COMPUTER

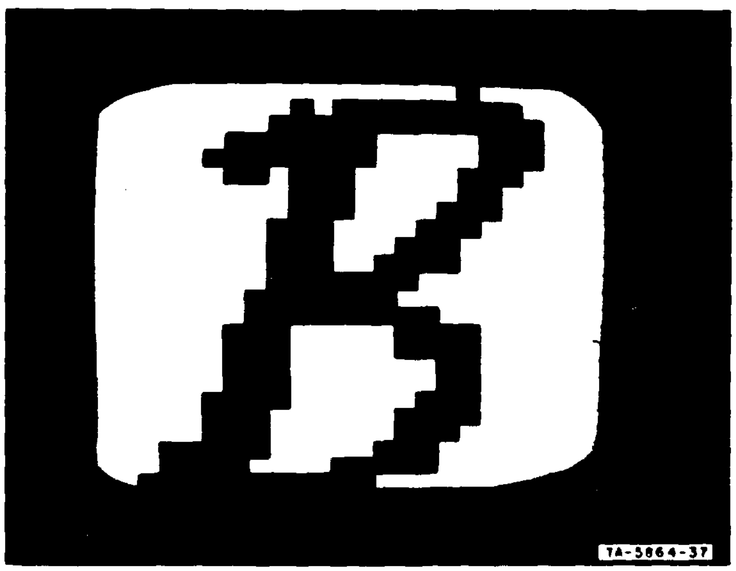

FIG. 4 TV MONITOR DISPLAY OF A HAND-PRINTED LETTER B

```
*************************
*                0      *
*        0 000000000    *
*       0000000000000   *
*      0000000    000   *
*     00000000    000   *
*      00 000    000    *
*         000    00     *
*         000   000     *
*        000   000      *
*        000  000       *
*        000 0000       *
*        0000000        *
*       0000000         *
*       000000000       *
*      000     0000     *
*      000     0000     *
*      000       00     *
*      000       00     *
*     0000      000     *
*     000      0000     *
*     000      000      *
*   00000     000       *
*   0000    00000       *
*  00000000000          *
*************************
```

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FIG. 5 TYPED REPRESENTATION OF A HAND-PRINTED LETTER B

D. Connection to the Preprocessor

The projection TV tube in the 1024-image preprocessor is connected to the TV chain and gated so that it receives and displays the TV picture when the output operation is being performed. A scanned image is sent out from the computer and presented long enough for the mask circuitry of the preprocessor to settle. The responses of the preprocessor are then dumped into the array of silicon-controlled rectifiers (SCR's), from which they are transferred to the MINOS input buffer. The responses may be used to train and test the MINOS II machine directly, or they may be sent to the computer for storage or classification by the CALM learning-machine simulation.

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Handprinting Recognition						
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Graphical Data Processing						
Visual Image Processing						

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